Archaeological experiments in fire-setting : protocol, fuel and anthracological approach

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ARCHAEOLOGICAL EXPERIMENTS IN FIRE-SETTING: PROTOCOL, FUEL AND ANTHRACOLOGICAL APPROACH

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ABSTRACT: From 1997 fire-setting experiments have been undertaken each winter in the Fournel silver mines at L'Argentière-la-Bessée (Hautes-Alpes, France). The objective is to work through this "process" to rediscover technical know-how, evaluate the combined role of the fire's intrinsic (fuel) and exterior (ventilation, pyre architecture) factors, and potential results. Beyond the strict environmental aspects, this process highlights methods of fuel management, fire practice and know-how, from the forest to the mine. The pyres are set against a hard native quartzite wall, in order to pierce a gallery 1,20 m high and 1 m wide, following the observed medieval network. As the archaeological-anthracological analyses suggest, the available timber species are *Pinus* type *P. sylvestris*, *Larix-Picea* and to a lesser degree *Abies* sp. The principal parameters are systematically measured and observed : timber weight, hygrometry, size of logs, pyre makeup (set against the quartz wall, in tower form, laid horizontally), fire dynamics and surrounding temperatures. The work face advance is evaluated and measured. Rock and charcoal residues are measured granulometrically and observed macro- and microscopically. The anthracology constitutes a catalogue of anatomic deformations in this specific context. The question is to define the variable(s) producing stigmata in order to open up study perspectives on the fuel operating chain. This communication examines the preliminary studies carried out during a master degree thesis and during scheduled archaeological excavations.
KEY WORDS: Mining, Fire-setting, Techniques, Fuel Management, Charcoal, Anatomical Signatures

RÉSUMÉ: Depuis 1997 des expérimentations de taille au feu sont menées chaque hiver dans les anciennes mines de plomb argentifère du Fournel à L'Argentière-La-Bessée (Hautes-Alpes, France). L'objectif est de pratiquer cet outil pour retrouver des gestes techniques, évaluer le rôle combiné des facteurs intrinsèques au feu (combustible) et extrinsèques (ventilation, architecture du bûcher) et les rendements potentiels. Au-delà d'un aspect strictement environnemental, cette entreprise tend à caractériser des modes de gestion du combustible, des pratiques et un savoir-faire du feu, de la forêt à la mine. Les attaques sont menées contre une paroi de quartzites non altérées et très dures pour percer une galerie en travers-banc, haute de 1,20 m. et large de 1 m., à l'image des portions observées dans le réseau médiéval. Comme le suggèrent les analyses anthracologiques archéologiques, les essences sollicitées (disponibles) sont *Pinus* type *P. sylvestris*, *Larix-Picea* et dans une moindre mesure *Abies* sp. Les principaux paramètres font l'objet de mesures et d'observations systématiques: poids du bois, hygrométrie, gabarit des bûches, confection du bûcher (adossé contre la paroi, en tour, couché), dynamique du feu et températures ambiantes. L'avancement du front de taille est évalué et mesuré. Les résidus de roche et les charbons font l'objet de mesures granulométriques et d'observations macro- et microscopiques. L'anthracologie permet de constituer un catalogue de déformations anatomiques dans ce contexte spécifique. Il s'agit de définir la ou les variables à l'origine des stigmates, pour ouvrir des perspectives d'études sur la chaîne opératoire du combustible. Cet article fait état des recherches préliminaires menées dans le cadre d'un Diplôme d'Etudes Approfondies et d'une fouille archéologique programmée.
MOTS CLÉ : exploitation minière, abattage au feu, pratiques, gestion du combustible, charbons de bois, signatures anatomiques

ZUSAMMENFASSUNG: Seit 1997 werden jährlich im Winter Versuche zum Abbau erzführenden Gesteins durch Feuersetzen in den Silberminen des Fournel in L'Argentière-La-Bessée (Hautes-Alpes, France) durchgeführt. Ziel ist, die Techniken dieses Verfahrens zu rekonstruieren und hiermit die jeweilige Wirkung stoffeigener Faktoren (Brennstoff) und äußerer Einflüsse (Belüftung, Schichtung des Brennholzes) sowie die Abbauleistung einzuschätzen. Über die Frage der Umwelt hinaus befaßt sich die Studie mit der Organisation der Verwertung des Brennmaterials, den Praktiken sowie den Kenntnissen des Feuersetzens, der Holzwirtschaft und des Bergbaus. Der Abbau des unverwitterten, sehr harten Quarzitgesteins beginnt an der Felswand und treibt in diese einen 1,20 m hohen und 1 m breiten Stollen vor, nach dem Vorbild der vor Ort vorgefundenen mittelalterlichen Systeme. Nach Maßgabe der anthrakologischen

Untersuchungen wurden hierzu *Pinus* vom Typ *P. sylvestris*, vgl. *Larix-Picea* und in geringerem Umfang *Abies* sp. verwendet. Hierzu werden die Hauptdaten gemessen und systematischen Beobachtungen unterzogen: Gewicht der Hölzer, Feuchtigkeit, Masse und Form des Scheiterhaufens (Schichtung gegen die Wand, Turmform, Legung), Feuer- und Temperaturentwicklung. Der Fortschritt der Abbaukante wird bewertet und vermessen, die Abplatzungen und Holzkohlereste gemessen und makro- wie mikroskopisch untersucht. Als Ergebnis der anthrakologische Studie liegt ein Katalog der anatomischen Verformungen in diesem besonderen Kontext vor, der Einblick in die unterschiedlichen auf das Gestein einwirkenden Mechanismen gewährt und somit Ausblicke auf die Waldwirtschaft und Holzgewinnung erlaubt. Unser Beitrag stellt die Ergebnisse von Voruntersuchungen vor, die im Rahmen eines Dissertationsvorhabens durchgeführt wurden.

STICHWORTE: Bergbau, Feuersetzen, Techniken, Praktiken, Holzwirtschaft, Brennholz, Brennstoff, Holzkohle, holzanatomisch

INTRODUCTION

When the wall-rock was particularly hard, fire-setting was the most widespread technique in the Middle Ages to extract the ore. Its success in practice does not show through in the written sources and the medieval iconography which are too lacunary and allusive. Only archaeology can bring new light, thanks to the architectural analysis of the works and examining the sterile granulometry and sedimentology. One of the most pre-eminent characteristics is the abundance of charcoal deposits, relics of the thousands of blazes which made it possible to open up and work the mine. These deposits constitute a mass of hard to interpret significant information because the perception of timber use through the human prism generates deformations. On the basis of this postulate, recourse to archaeological experimentation is inevitable. It should improve comprehension of the ground, clarify the interpretation of operational dynamics and make it possible to characterise modes of management of the deads and fuel. These prospects open possibilities of paleo-ecologic, technological and practical interpretations.

Except for laboratory tests realised during the 19th and at the beginning of the 20th c. (DAUBRÉE 1861, HOLMAN 1927), experimental fire-setting was initiated by Welsh archaeologists to study the technical incidences of tools made from stag antlers and stone on rock weakened by fire, in proto-historic mines (CREW 1990, LEWIS 1990, TIMBERLAKE 1990b). At the end of the 19th c., in the nineties, pioneer tests in France were carried out in the mines of Goutil-L'Argentario and at Melle. They showed the real potentialities of experimentation to study the interrelationships of the mine and the forest (DUBOIS 1996, TEREYGEOL 1998).

Figure 1. Experimental operating area (modern workings, Fournel mines).

At L'Argentière-La-Bessée, 66 experiments were led during the 2002-2004 campaigns whilst profiting from a pluri-disciplinary co-operation on the interface of human action on the environment. They constitute the first steps of an in-depth study on wood and its specific uses for the mining activity in the Fournel valley. The experimental site is located quite far underground, in the engine chamber, chosen for its accessibility and the possibilities of ventilation. The transport of various materials, wood loads and tools is facilitated by roomy access, characteristic of the modern works. A comfortable workspace facilitates scientific follow-up of pyre combustion and data recording, by eliminating the risks caused by choking smoke (FIG. 1).

The objective of this contribution is not to develop an exhaustive presentation of the fire-setting experimental work in the Fournel for several years now, but to clarify the specific study of fuel and the charcoal residues to open a reflection on the mining uses of fire and the economy of timber. This original approach lies in the broader framework of current research on the history of technical know-how and types of mediaeval resource management.

SCIENTIFIC FOLLOW-UP OF EXPERIMENTAL SIZE FIRE-SETTING

Periodicity of the experiments

To profit from good ventilation, experiments are held during the winter. Based on the initial work done since 1997, the rate of one fire per day was selected to allow the cooling of the rock face between each fire, and better recording of the data (collecting of residues, sifting, sorting, weighing). Indeed, at the time of the first series of experiments, the fires were launched continually for 33 hours so as not to let the rock face cool down (Ancel and Marconnet 1997). In the same manner, the second series of fires in 1998 was led uninterruptedly for 40 hours. Finally, the 1999 experiments went on for 6 days, with 4 to 6 continuous fires per day (Ancel 2000). These remarks pose the problem of the rate/rhythm of fire-settings in the Fournel between the 10th and 14th c. Under certain conditions, they could be carried out uninterrupted as in the mines of Kongsberg (17th-18th-19th c.) or, during a public holiday or on Saturdays or the day before to avoid accidents by suffocation as in the mines of Rammelsberg (Hartz) and in the medieval mines of Massa Marittima (Tuscany). But these isolated mentions, specific to an ore level and a technical framework, cannot be generalised for all sites and all periods (Simonin 1859, Collins 1893, Berg 1992, Dubois 1996). Moreover, the effectiveness of a fire burnt against a cold rock face must be tested. The strong variations in temperature on the surface of the rock can constitute an important factor (Collins 1893: 90-91).

Our initial objective was to dig out of a solid rock wall, a gallery of “medieval type” whose height and width would not exceed 1.5 m.

Recording of the data

To profit from a corpus of recurring and statistically exploitable data, a record card was created and improved progressively during the experiments. It is composed of two distinct parts: during the experiment and the assessment. In general, an experiment is spread out over 24 hours. It begins with the selection of wood, stored under cover, outside the mine. Underground, the logs are split and prepared on a special surface. Each log is measured and weighed. The pyre is lit around midday. The wood is consumed on average for three-quarters to one hour. Cooling time of the hearth and the rock takes the remainder of the day and all the night. The next morning is devoted to collecting the fragmentation residues, with manual purging of the weakened rock, weighing of the residues (fragmentation and purging) and with construction of the pyre for the following fire, all carefully described with sketches. The experiments undertaken in 2002-2004 required, in all, six working weeks under ground.

The card has on the recto, a table for the course of the experimentation: statement of the ambient temperature at various stages of the experiment (arrival, lighting-up, fragmentation) and timing of the length of pyre burning. This recording makes it possible to characterise the rate/rhythm of combustion, the heat and radiation of the fire (calorific release of energy which heats the atmosphere). This method is provisional, awaiting installation of thermal probes to measure variations in temperature of the rock face and in the hearth.

A second table is intended for recording the weight and size of the logs. Logs of different sections are split, or more rarely sawn, according to the type of pyre to raise. The kind of the wood is stipulated. The pyre has a specific insert for description of the layout of the hearth (floor), the pyre arrangement, steepness and contact with the rock face, the sides and vault of the gallery. Lastly, the bottom of the card is devoted to description of lighting-up and the progression of the pyre. This paper-work is reinforced by photography every 5 minutes.

The second part of the experiment corresponds to treatment of the residues. The verso of the card is composed of three tables reserved respectively for the charcoals, the rock fragments and the residues from manual purging.

A first stage consists in recovering the unburnt, half-burnt, or carbonised logs. These residues are weighed. On the postulate that the Old Men managed energy as well as possible, this residual fuel is re-used in further fires. In the same way, charcoal resulting from the incomplete combustion of the large logs are the subject of a first rough grading corresponding to anything more than one centimetre. These coals preserved in the dry are potentially recyclable for domestic or artisanal activities. A second grading consists in collecting the maximum of residual coals to reduce the work of sorting and fragmentation post combustion. Finally, the last coals are hand-sorted during spoil sifting. The filtered fractions are: > 10 mm, 10-5 mm, 5-2.5 mm, 2.5-1.6 mm, 1.6-1 mm, < 1 mm.

The fractions smaller than 4 mm are excluded from the total weighing of residual coals and are classed with sand and dust. These millimetre-length shards result from fragmentation post combustion of fragile coals whose oxidation was already quite advanced. The coals collected from each experimentation are the subject of sampling to be subjected to microscopic analysis. The advance of the rock face is measured in the form of a longitudinal profile.

Description of a standard experiment: in practice

The experiment begins with provision and choice of fuel. In 1999, the wood had been stored in the mine near the experimental rock face. Output dropped gradually and became catastrophic on the sixth day. We then noted that the logs had become wetter because of their underground stay (to 99% of ambient humidity). Since then, we adopted the precaution of bringing the wood into the mine at the last moment. The logs are transported in bags and care is taken not to unnecessarily dirty or wet them.

On the spot, the logs are split according to the objectives of the experiment. In our configuration, the size of the rock face limits the quantity of wood to 70 kg. The splinters are recovered for lighting-up. The kindling burns in a few minutes and does not play a role in the attack of the rock but is determinant for fast firing of the pyre. It is thus important to prepare at least 2 to 3 kg of kindling.

The pyre should be prepared carefully as a good firing is related to the way it is made. The joining of several logs orients the flames, sometimes even making a very effective "blowtorch" effect. A log face to the wall can screen and protect the rock. Compact stacking lengthens fire time, and on the contrary a ventilated provision burns it very quickly. At the base, setting of a kind of floor allows good ventilation of the pyre, at least until its collapse. The structure must be made up so that it resists collapse longest; a mixture of thicker and smaller logs reconciles strength of the blaze and solidity of the pyre. As the cavity open to the fire has round walls, it is necessary to accommodate this in building a stable pyre; blocks of rock can be used for this purpose (they should not be counted in residue weighing!).

During the construction of the pyre, one should not lose sight of the objective of the experiment: to advance the boring of a gallery. If one "stuffs" the wood anyhow into the cavity, one will enlarge it, without hardly advancing the work face.

We chose two types of pyre construction. The "lying" pyre is composed of a floor which is based on the concave base of the rock face on which are piled up, in a more or less parallel way, the logs inclined against the face. The direction and the slope of the logs will direct the flames towards such or such part of the cavity: the face itself, the vault, the left or right-hand walls. They can also be laid out in a cone to try to concentrate the flames towards a more precise zone. The "tower" pyre is composed of several stages of perpendicularly piled up logs (Fig. 2). The flames will thus tend to rise on all sides. If one arranges a kind of chimney in the centre of the tower, one obtains a blowtorch effect towards the vault. For these two types of pyres, one can also make a "screen", of broad and regular logs which are laid against the pyre and which prevent the flames from escaping towards the opening. They thus ensure progressive falling-in towards the rock face.

From one experiment to another, the size of the logs is never identical, nor the disposition of the fire, nor its intensity, nor the advance of the rock face, etc. Thus, by definition, each experiment is unique and their duplication is inevitably relative.

For convenience, lighting-up is done using newspaper and fruit-box slats. It is not very authentic, but there is no incidence on the objectives. On the other hand one notes that remainders of this kindling are found in the residual hearth at the end of the experiment.

If the kindling is judiciously placed, the pyre blazes up in a few minutes. The fire intensifies so much so that the flames lengthen on the vault of the cavity, then lengthen more and lick up to nearly a metre upward on the gallery wall. The fumes stagnate a little at the ceiling, then escape by a higher opening, thanks to the ascending draught which traverses the mine in winter. The fire blazes thus for 10 to 20 min, then the flames drop and stay within the cavity. It is often starting from this decrease of the flames that the phase of fragmentation begins.

The fragments of rock detach from the rock face, sometimes flat shards, sometimes blades of 10 cm surface, accompanied by dry crackings, different from those

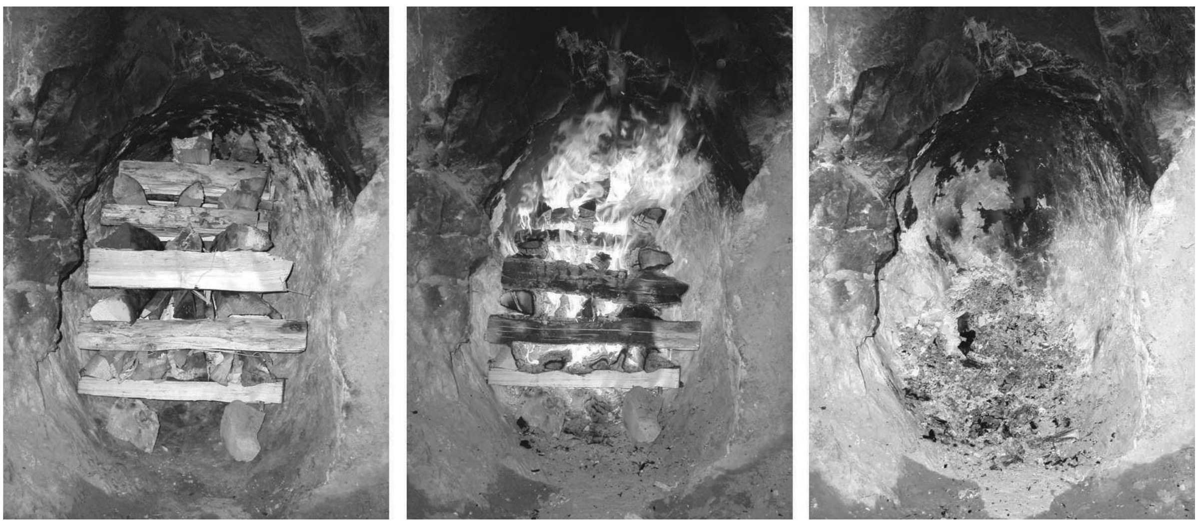

Figure 2. Experiment n°7: example of a "tower" type pyre.

The average humidity of wood								
Time of drying	Steres left in open air		Steres stocked under shelter after 3 months in felling area		Logs of 33 cm stocked under shelter 3 months after cutting		Logs of 33 cm stocked under shelter from the shaping	
	Q	L	Q	L	Q	L	Q	L
0 (H% init.)	75	78	76	78	75	78	73	76
3 months	48	62	48	61	44	61	36	40
6 months	37	46	32	45	29	35	25	29
9 months	33	38	27	37	26	28	24	28
1 year	26	35	26	33	25	27	23	27
1 year 1/2*	18	27	18	21	17	17	15	16
2 years	16	24	16	17	16	14	14	13
2 years 1/2	15	24	15	18	15	14	13	13
Delourme Olivier Informations from DEVILLE								

Figure 3. Evolution of the average humidity contained in timber after cutting.

which can occur during wood seasoning. Many of these fragmentations take place on the part of the face hidden by the pyre. On the other hand, they are quite visible from the ceiling and present a sometimes spectacular explosive character; shards of heated rock are projected up to 5 meters of distance from the hearth. The fragmentations can sometimes follow one another quickly at the time of phases of "crisis" where projections can cover thickly the front of the hearth (Fig. 2). On the sides, one observes crackings which gradually separate blades of thick rock. The fragmentations are not always spectacular, however a discrete attack operates behind and under the pyre.

After three-quarters of an hour, the burnt pyre starts to subside and tends to form an ember cluster mixed with the fragmented rock. The fragmentations are spaced in time then cease. The embers still flicker for more than an hour.

The following day, the residues of the hearth are treated. Sometimes, there remain fragments of half-burnt logs. Large charcoals mark the site of the last consumed logs and split up as soon as they are touched. During the cleaning of the hearth, one observes a great abundance of residual coals, about 10 to 20% of volume, without any comparison with what one observes in archaeological steriles. One also observes the fragmentation which happens more discreetly in the lower part of the cavity, hidden by the pyre. On the floor very thick shards are detached.

After this first cleaning, the walls are hammered to be purged. Certain zones are healthy and sound clear under the blows of the mallet, either because they were not attacked by fire, or because they were purged "naturally" during the phase of fragmentation. Other zones sound "hollow" and the masses of shards fall easily. The microfractured zones appear to resist fragmentation and must be cut down during the purging. Dust is significant. Sifting of the product shows that close to 1/5 of the cut down rock is composed of particles smaller than 2 mm.

ASSESSMENT AND LESSONS

Three "wood factors" can be put forward for the conduct of fire-setting: humidity content, size, the type and an "extrinsic" factor of combustion, the installation of the pyre.

The humidity factor

The water content leads to a variation of the calorific value of the wood, with effect on the temperature from combustion and models the behavior of the fire (persistence and height of the flames). Moreover, the variation influences the duration of calcination. Good management is for example essential for fires which must "brood" a long time or blazing fires which will be consumed quickly. Experiments undertaken in 1999 show increasing fall of output which was related to fuel storage in the mine, where ambient air is saturated with moisture. This factor thus intervenes directly on rentability of fires. In accordance with the written sources and practice, it is obvious that using green heartwood is excluded for the fire. Indeed, in the Middle Ages, the conditions of lighting and ventilation could prove very difficult in major workings. This type of wood can nevertheless be used exceptionally, notably for feeding vigourous fires carried out in the open air (working starts, scrapings) for which any available timber is not negligible. The wood used for the experiences carried out in 2002 was "dry". It was delivered by a local wood merchant and stored in the form of coarsely split logs under a sheet exposed to the south. As the wood is generally quite cold because experiments are undertaken at the height of the winter, the exact water content could not measured with an electrical appliance, but it can be evaluated in a theoretical way. A log is sold dry with a water content included/understood in between 22-23 and 18%. Dried in the open air, it preserves a water content which is established between 15 and 20%. the logs used in 2003-2004 probably reached a more reduced fork with rates ranging between 15 and 18%. They could be a factor supporting the significate increase in outputs at the time of these experiences. The wood which remained is unused, these rates can be reached theoretically after a storage period under shelter or in the open air for 2 years to 2 years and half (Fig. 3). According to archaeological data, the miners of the Fournel utilised quasi exclusively coniferous trees, they thus had interest in felling in summer, when water content is the least significant. However, the traditional period of cutting of coniferous trees is at the height of winter (January-February), to avoid the abundance of resin in which they abound in spring and in summer. The obtention of a seasoned wood thus constituted a constraint, because it was necessary to be able to store it in large quantities preferably with shelter. As it is twice more profitable to dry on site the wood split in quarters rather than logs, one can consider a true operational stock preparation line of fuel upstream of the mining works. Analysis of carbonaceous residues can give elements of interpretation, thanks in particular to observation of deteriorations (fungic attacks, open slits of insect withdrawal). Elements of mycelium were observed in the cellular structures of the archaeological samples. Their study is in hand and will have to determine the theoretical time of wood stockage wood.

The factor of size

It is possible to make blazing fires with dense wood by varying its section and water content. The more the log is thin the more the gases of combustion ignite quickly. However, to make a vigorous and durable fire, the wood surface for the flames must be significant. Fires of faggots blaze up very quickly and grow rapidly in temperature but their duration of burning is reduced. To obtain a fire long burning with a high temperature continuously, it is essential to manage the size of wood and rough-hew it according in particular to their strategic role in the fire architecture (wood of support, lighting up, reinforcements and filling). The data enregistered during the experiments carried out in 2002 (1 to 31) show that the section of the logs and the quarters constitutes a measure which intervenes in the rentability of fires. The best ratios (quantity of wood put at fire/cut down rock) correspond to the average sections of the logs ranging between 15 and 18. The lower or higher sections have not given very profitable results. But, during the following experiments (31 to 66), more significant calibres were used, increasing significantly the average of the sections (26 to 57). Fires of significant average sections proved very profitable (Fig. 4 and 5). The management of this parameter thus plays a role more determinant than the quantity of wood sawn up. The use of large quantities of small sections is less profitable than a smaller fire, but associating large sections in combination with smaller. Inversely, to improve the output of fires of faggots, it is necessary to use a great quantity of wood, which can imply despite everything a useless enlarging of the cavity. In the case of the tower fires, the fire must flame upwards around the tower to attack the vault of the gallery. It is thus necessary to associate larger sections with smaller ones.

The factor of species

After the criteria of size and moisture, there exists a variation of the properties of the combustion according to the species with water content varying to equal morphology. The inflammability a log is influenced by the density of the wood, its molecular composition and its content of minerals. The calorific value changes very little from one species to the other, the variations are essentially due to the chemical constitution of different species. The spruce used for the first 15 experiments is a tender light wood. Its density is low (0.45). The larch and the woodland pine used for the following experiments (in association or independently), presente a definitely higher density (0.62 and 0.55) (Fig. 4). The resin contained in these species have a very high calorific value which generate good inflammability, while the biogenic salts, also called “ashes”, influence this property negatively. The more their rate is weak the more the wood will ignite quickly. This compound is present at the level of 0.3% in the woodland pine, 0.21% in the spruce and 0.17% in the larch. In the last analysis, the calorific factor varies very little between these three species. It is slightly higher in the spruce (4622 Kcal/kg) and quasi equal in the woodland pine (4556 Kcal/kg) and the larch (4597 Kcal/kg). In comparison with the experimental data, the species parameter does not directly influence the output of a fire. It appears clearly that the parameters “rate of humidity” and “size” are major. This assumption makes it possible to exclude it from a preferential selection of a species compared to another and validates the paleoecologic approache to mining charcoal. It is true that the coniferous trees are very inflammable, they are used also for the making of torches (Magnus 1561, Castelletti and Castiglioni 1993). The use of small sizes of light deciduous trees obtains the same result. For fire setting, the peremptory necessity for a bright burning fire is not shown. The miners could use blazing fires and brooding fires according to the technical constraints to surmount, like cutting down the ceiling or the foot of a gallery. A choked fire allows transfer of heat by conduction. There is a transmission of energy of fuel towards the rock. Its propagation velocity depends on thermal conductivity over the quarzites. The heat transmitted by the flames is interesting when its radiation is channeled by the saw length. The radiation led to spectacular cracking, accompanied by projection of plates of rock heated with white. These approach the last point which constitutes in our eyes an extrinsic factor: the installation of the logs.

The factor of fire construction

Starting from the iconographic data of the extreme end of the medieval time and modern period (general works), two types of pyres and some alternatives were used: high towers (Fig. 2) (with or without screen) or leaned (more or less vertically) against the wall of the coal face. From the strict point of view of the outputs, the first method is on average less profitable than the second (Fig. 5). From a strategic point of view, the use of these two techniques is complementary. These results are not surprising but with practice, the towers leaned and proved more direct to reach the mining objective. The tower constitutes nevertheless a good means to attack the top and to widen the cavity. Its use is effective or even more profitable to open and widen a cavity. These observations show the interest of a "slow" fire whose attacks are less spectacular but prove efficient to bore the floor and to tackle the face. Management of the orientation and the slope of the logs also makes it possible to target the attack to the left or right-hand sides of the gallery. These principal parametres are obviously not the only ones to intervene on the fire strength. The ventilation (lack of air decreases the temperature of combustion), the ambient temperatures (between the interior and the exterior) and the morphology of the rock constitute as many new factors. It seems complex to test all information recorded with classic statistical tests because the influencing parameters are too numerous. Such a step requires recourse to factorial analysis of correspondences (AFC) to determine the characters whose impact can be measured on the 66 experiments. Necessary parametres are the water content, the section of the wood, the number of logs, the species, weight and morphology of the logs, the surrounding temperature and the temperatures of combustion. This step will be possible when all the parametres can be measured. In fact, the temperatures of combustion and the gradient of rise in temperature constitute the link lacking in this experimental study. The question has to precisely determine from which temperature the rock cracks and is split. This information can clarify the problem of which fire to use: "bright burning" or "slow" fire. Does heat have to emerge gradually to do profound heating or is necessary it that it gets bright violently to cause a thermal shock ? To carry out a good attack thus requires control of the state and morphology of the wood. The constraints, techniques and urgent economic requirements imply a rigorous management of this raw material. In this direction, mining is implicitly related to forestry development.

ANTHRACOLOGICAL ANALYSIS OF EXPERIMENTAL CHARCOALS

Beyond taxinomic determination, anthracological study allows a specific insight on fuel and its uses. From this point of view, precursory work on charcoals resulting from paleolithic hearths and laboratory experiments to reproduce the same deformations, highlighted the interest of analysis of anatomical modifications of the structure of wood in terms of economy of timberings (Théry-Parisot 1998, 2001). The archaeological charcoals found in the mines of Fournel present anatomical deformations which were observed in a recurring way on the transverse and radial levels. They are mainly radial slits often open, cellular fusions more or less partial (vitrification) and localised tangential crackings on the level of the rings of growth. Within the framework of our approach, it is possible to check if these deformations are reproductible in an experimental context. The goal is to determine the causes responsible for their appearance under the effect of carbonization in this specific context, to open prospects for studies in terms of practice. But as the principal parametres of the experimentation are not completely controlled, the possibilities of interpretation are limited. Despite everything, we considered it necessary to announce our preliminary observation to continue to feed reflexion on this subject. A sampling "test" of experimental residual coals was carried out to constitute a first inventory of recurring and significant markings. The anatomical study was carried out on 170 experimental coals resulting from 17 experiments. Measurements of the deformations (slits and cracks) and their statistical counting were not considered to be necessary because the studied corpus is incomplete. The first observations are nevertheless worthy of comments.

The radial slits

A little more than 60% of the analyzed experimental samples present radial slits often open. One finds 65% of the individuals presenting such deformations for the experiments carried out with spruce and 66% of the individuals for those carried out with pine and/or larch. The frequency of the slits is significant with the three species. These strong percentages cannot be related to the use of a green heart or wet wood. Experiments carried out in laboratory, by controlling the parametres of carbonization perfectly, show that it is not possible to determine starting from this only criterion the use of a green heart or a seasoned wood (Théry-Parisot 2001: 56-68). The appearance of shrinkage cracks is then

n°	Logs	Type	Species of wood	Average	Sect°	Stan. deviatio	Wood stacking	Wood burned	Charcoal	ch/wood	fire-setting	Purge	Rock extrac.	Ratio
1		A	E				31,0	30,8	0,4	0,013	5,013	12,279	17,29	0,56
2	22	A	E	1,1	15,4	3,1	23,1	23,0	0,4	0,018	5,047	6,823	11,87	0,52
3	22	A	E	1,3	17	3,1	28,4	28,1	0,4	0,015	4,03	9,918	13,95	0,50
4	28	A	E	1,1	15,1	3,6	32,1	32,1	0,4	0,013	6,294	7,588	13,88	0,43
5	27	A	E	1,2	16	3,2	31,1	31,1	0,4	0,014	7,299	9,431	16,73	0,54
6	23	A	E	0,9	16,1	3,9	21,8	21,7	0,5	0,022	5,643	4,578	10,22	0,47
7	19	A	E	0,9	16,9	4,4	17,3	17,0	0,3	0,018	4,365	2,935	7,30	0,43
8	36	T	E	0,8	18,3	5	29,4	28,4	0,4	0,013	12,924	8,02	20,94	0,74
9	25	T	E	0,9	19,5	5,8	23,5	23,4	0,2	0,009	8,1	7,68	15,78	0,67
10	31	T	E	0,7	19	5,7	22,3	22,3	0,4	0,020	8,566	11,902	20,47	0,92
11	27	T	E	1,0	17,3	6,1	26,9	26,9	0,4	0,014	7,59	7,47	15,06	0,56
12	21	T	E	1,1	17,3	5,3	22,3	22,0	0,3	0,013	4,175	4,638	8,81	0,40
13	23	T	E	1,0	17,8	5,2	24,1	24,0	0,3	0,012	8,13	6,73	14,86	0,62
14	27	T	E	1,2	18,3	5,6	32,2	32,2	0,4	0,013	7,823	8,157	15,98	0,50
15	24	T	E	1,2	17,5	4,5	28,8	28,6	0,5	0,017	9,585	9,68	19,27	0,67
16	33	T	PM	1,0	18,8	4,9	34,5	34,4	0,5	0,014	7,275	9,79	17,07	0,50
17		T	PM				30,0	29,5	0,6	0,020	6,425	6,425	12,85	0,44
18	25	T	PM	1,2	21,9	8,8	30,6	30,0	0,6	0,019	4,951	4,635	9,59	0,32
19	26	T	PM	1,1	19,1	7,8	29,6	29,5	0,7	0,023	9,13	12,155	21,29	0,72
20	28	T	P	1,0	17,6	4,6	26,7	26,4	0,6	0,023	5,299	3,99	9,29	0,35
21	29	T	M	1,0	18,4	6,3	28,9	28,8	0,9	0,031	11,934	5,486	17,42	0,61
22	23	T	P	1,3	20	7,2	29,6	29,4	0,7	0,023	8,375	5,984	14,36	0,49
23	29	A	M	0,9	18	5,2	26,1	25,5	0,6	0,022	7,555	5,066	12,62	0,49
24	17	A	P	1,3	18,3	4,7	21,7	21,0	0,5	0,021	9,372	5,906	15,28	0,73
25	22	A	M	1,0	17,9	4,6	22,6	21,7	0,6	0,028	8,005	6,155	14,16	0,65
26	20	A	P	1,1	15,6	4,9	21,1	20,4	0,5	0,023	4,12	3,925	8,05	0,39
27	20	A	M	1,6	22,7	9,3	31,3	31,1	0,7	0,021	13,055	6,225	19,28	0,62
28	19	A	P	1,2	18,4	8,6	22,6	22,0	0,7	0,030	5,36	4,295	9,66	0,44
29	34	A+	MEP	1,6	22,5	7,4	53,9	52,9	1,1	0,021	30,315	17,775	48,09	0,91
30		A	MP				35,0	35,0	0,5	0,014	37,46	17,46	54,92	1,57
31	20	A	M (P)	1,7	26	10,4	33,8	33,4	0,5	0,015	12,1	4	16,10	0,48
32	17	A	M (P)	2,1	29	20	35,9	33,7	0,6	0,015	13,6	4	17,60	0,52
33	17	A	M	2,5	34,3	12,8	42,6	41,9	0,7	0,017	15,4	5,2	20,60	0,49
34	20	C	M	1,5	23,9	9,3	29,7	28,9	0,7	0,023	11,5	9,6	21,10	0,73
35	16	C	M	2,0	31,8	15,4	31,5	30,2	1,0	0,030	6,2	6,7	12,90	0,43
36	21	C	M	1,5	25,2	13,7	31,7	31,1	0,6	0,017	6	6,5	12,50	0,40
37	25	T	M	2,2	31,9	19,2	53,9	53,6	0,7	0,013	15,7	18	33,70	0,63
38	19	T	M	3,1	43,6	14,9	59,1	58,7	1,0	0,017	21,3	13,2	34,50	0,59
39	20	T	M	2,7	41,3	21,8	53,4	53,3	1,0	0,018	13	15	28,00	0,53
40	14	A	M	3,0	40,5	26,9	42,5	40,1	0,4	0,010	10,6	4,9	15,50	0,39
41	11	A	M	3,6	43,6	19,3	39,4	38,3	0,8	0,019	19,2	10,25	29,45	0,77
42	16	A	M	2,5	36,1	17,2	40,6	39,6	0,3	0,009	19,4	9,1	28,50	0,72
43	27	TE	M	2,2	36,1	14,6	60,3	60,3	0,9	0,015	24,6	21	45,60	0,76
44	30	TE	M	2,2	41,8	20,4	65,3	64,0	0,6	0,009	21,9	15	36,90	0,58
45	28	TE	M	2,0	42	19,7	56,9	55,8	1,2	0,020	12,8	9,3	22,10	0,40
46	25	TE	M	2,2	39,1	14,1	55,1	24,9	0,9	0,017	11,3	9,25	20,55	0,83
47	23	TE	M	2,6	39,5	20,1	58,9	58,4	0,7	0,011	19,9	19	38,90	0,67
48	19	A	M	2,0	30,3	18,7	38,6	37,9	0,7	0,018	15,9	4,3	20,20	0,53
49	20	A	M	2,3	33,4	21,1	46,5	46,4	1,3	0,029	14,23	5,14	19,37	0,42
50	19	A	M (P)	2,2	30,5	14,4	40,9	40,8	0,9	0,023	15,765	7,805	23,57	0,58
51	18	A	M	2,9	38,5	16,7	53,0	53,0	1,3	0,025	24,009	13,355	37,36	0,70
52	27	A	M	1,7	24	9,5	46,0	45,6	1,2	0,025	9,815	10,185	20,00	0,44
53	15	AC	M	3,3	51,5	29,9	48,9	48,7	1,2	0,024	26,175	8,97	35,15	0,72
54	17	CT	M	2,8	37,6	26,8	47,7	47,2	0,7	0,014	24,44	14,655	39,10	0,83
55	13	C	M	3,3	40,1	19,7	43,5	43,2	0,7	0,016	11,6	9,76	21,36	0,49
56	12	C	M	3,1	37	21,9	37,1	36,6	0,6	0,016	9,96	5,535	15,50	0,42
57	12	C	M	3,3	44,2	25,2	40,1	37,5	0,3	0,007	12,23	6,2	18,43	0,49
58	12	A	M	4,0	49,6	30,5	48,0	47,9	1,1	0,024	17,99	9,1	27,09	0,57
59	12	A	M	3,2	36,7	23,1	38,6	37,8	0,8	0,020	16,207	9,708	25,92	0,69
60	20	A	M	3,3	41,5	26	66,7	65,2	1,2	0,017	61,513	24,63	86,14	1,32
61	10	A	M	3,0	43,7	27,7	30,0	28,4	0,7	0,023	4,965	6,92	11,89	0,42
62	13	A	M	5,3	67,6	26,5	69,3	68,8	2,2	0,031	57,12	26,34	83,46	1,21
63	15	A	M	4,0	46,3	25,9	59,7	59,7	1,7	0,028	35,04	25,78	60,82	1,02
64	13	A	P	3,6	47,2	14,5	46,9	46,9	0,3	0,006	19,59	16,815	36,41	0,78
65	17	AC	M	4,2	52,7	23,3	71,4	71,4	1,7	0,024	54,8	19,9	74,70	1,05
66	13	A	M	4,6	57,4	19,3	60,3	59,7	1,1	0,018	23,5	13,9	37,40	0,63

Ratio > 1	E = *Picea abies*	A = standing wood	AC = standing wood-lain wood
Ratio > 70 < 1	M = *Larix europaea*	T = tower	CT = lain wood-tower
Ratio > 50 < 70	P = *Pinus sylvestris*	C = lain wood	
Ratio < 50		TE = tower + screen	

Figure 4. General table of measurements taken during the fire-setting experiments.

interpreted as the effect of several factors combined, different from one species with another. Indeed, the behaviour of wood on fire depends, upstream, of its particular characteristics and, downstream, of the whole of variables of carbonization. Our results tend to show for the three species used, a regularity of the occurrence of splits. Consequently, the factors of carbonization seem significant. To validate this assumption, it is necessary to record the temperatures in contact with the rock and in the hearth, as well as the gradient of rise in temperature. The

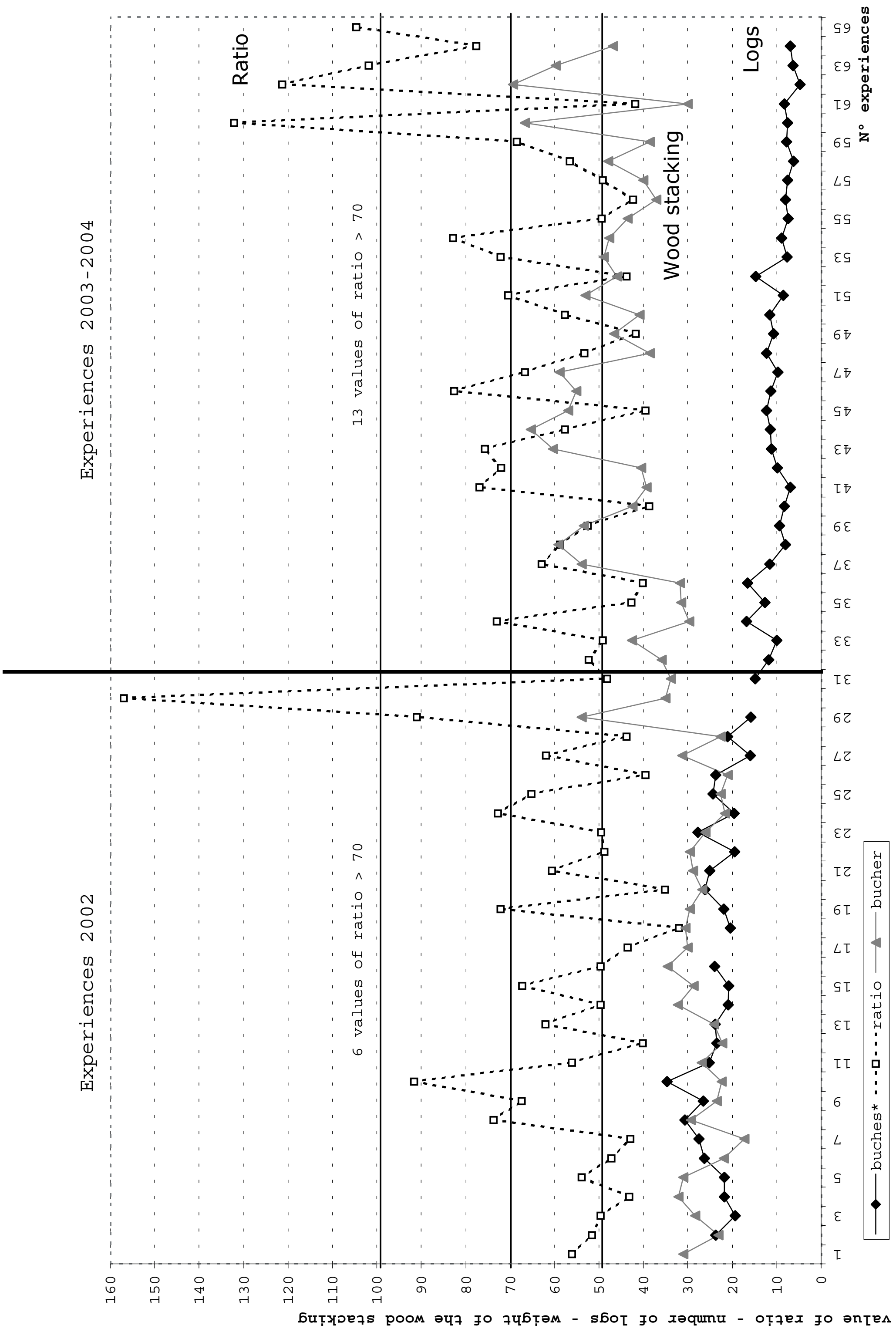

Figure 5. Comparative chart of pyre weight, number of logs and ratio for the 66 experiments.

observations carried out by other authors show that the temperatures can easily go up up to 800 and 900 degrees in context of fire setting. The experiments undertaken in the laboratory by I. Théry-Parisot were limited to 750 degrees. It is thus not excluded that higher temperatures associated with a confined atmosphere are at the origin of the phenomenon. These remarks propose the need for parallels to studying the appearance of the deformations within the framework of archaeological experimental analyses carried out in laboratory.

Vitrification

Vitrification is the second deformation observed in a recurring way in the experimental samples. This phenomenon regularly announced by anthracologists is often associated with artisanal contexts like residual deposits of charcoals or the hearths of furnaces of potters (reducing cooking). Some see the result of a thermal shock there (water sprinkling for example), others determine the marks of the carbonization of a green heart or wet wood. To include/understand the origin of this phenomenon thus constitutes a key of interpretation to characterise stages of the operational chain of fuel and know-how of fire. This deterioration is caused by the fusion and homogenisation of the anatomical structures of wood which lead sometimes to the disappearance of certain criteria of determination. The seen samples have a vitreous aspect, shining and a globular structure very characteristic, but this level of degradation remains specific. Analyzed experimental charcoals contain a high percentage of partially vitrified fragments. Indeed, more or less advanced stages were distinguished. For a portion of them, the woody cells present a slightly vitreous aspect, perceptible out of radial cut. Others, more difficult to break manually, present a total fusion of the anatomical elements producing a slag aspect which seldom reaches all the mass of the sample. The most deteriorated samples come from wood which had evacuated a fluid substance, at the time of the phases of drying and dehydration, become blackish with the outburst of the carbon dioxide. It is probably to do with the combustion of the resin which forms sometimes significant pockets in woody fibres. The coniferous trees are gorged with it in spring and in summer. Raised at high temperature, they could have an impact on the state of the charcoals. In this case, if these deformations are generated by abundant resin, their determination could offer indications over the season of cutting. It thus releases a true archaeological potential from this type of approach in particular with regard to the “signatures” of the practices of supply wood and cutting to fire. The experiments show very clearly that the specific methods of this technique generate notorious phenomena on the level of the anatomy of wood. However, the control of all the parametres which influence the behaviour of wood to fire and the output requires a considerable material investment (thermal probes and analyser of images).

Prospects: crossed glances with archaeology

In continuity with this study, is the question of weaving bonds between experimentation, groundwork and anthracologic analysis. The mine constitutes an original archaeological framework which imposes adapted methods. It is in particular a question of specifying potential production in charcoal residues and of evaluating their level of representativity in terms of provision territory and practices. A recording of the quantities produced for each fire was carried out for grainage higher than 10 mm, 10-5 mm and lower than 5 mm. It appears very clearly that pine and larch produce more residues than spruce. The quantity of charcoals obtained does not depend on the quantity of wood put on the pyre but on the type. One should not however not lose sight of the fact that the humidity factor which can exploit a considerable role the reduction of mass and the number of fragments (Loreau 1994). A test of X^2 shows that the distribution of the characters “quantity of wood” and “production of charcoal” differs in a highly significant way with a probability higher than 0.001. In the same way, the fine fractions increase to a significant degree with the use of pine and larch. There is thus a differential production of residues which depends partly on the species. The conditions of combustion influence in a more or less implicit way the production of charcoals in particular in the case of “brooding” fire. The question of more precisely defining this remark will depend on factorial analysis of the correspondences.

CONCLUSION

This contribution establishes the bases of an experimental protocol of the size to fire and establishes potential work directions. Indeed, this technique proves much more complex than the iconography and the texts make it appear. Access to know-how and practice by experimentation awakens a true “knowledge of burning” and “knowledege of managment” of fuel which today is completely “diluted” and skewed by uses of fire for pleasure and authenticity. Admittedly archaeological experimentation constitutes a working tool which is still imperfectly controlled and always used advisedly. Nevertheless, repetition of the protocol, scientific follow-up of fires and multiplication of tests to solve the various technical difficulties, make it possible to avoid the subjective character which is often charged to it. Gestures and skills are acquired gradually and highlight a long operational chain which starts with the provision of fuel and its storage, then continues with choice of wood and its preparation, bringing into the mine, construction of the pyre and its lighting, and finishes with treatment of the products, purging, sorting and storage of residues. The minerallurgic operational chain then takes over. Analysis of the products of experimental fragmentation, compared with that of the archaeological steriles in particular, highlights the complexity of underground procedure (Ancel *et al*, in press). The outputs obtained, probably quite poor taking into consideration those which were reached by experienced minors, are useful in the reflection over working time, considerable for the comprehension of operational dynamics and exploitation strategies, and also for the potential impact on forest dynamics.

Wood was a paramount energy source, of which it is necessary to understand the context. Perfect knowledge of its properties and management, adaptation to environmental possibilities and technical constraints, enable it to be used in an effective and very profitable way. The experiments highlight factors independent of the species validating a paleo-ecologic approach to the residues of mining activity. It helps to reconstruct the evolution of a medieval industrial landscape. Concerning forests, archaeological charcoals truly constitute the only source of information. The experimentation clarifies our perception of the landscape and allow reflection on the relevance of the archaeological charcoal deposits and their representativity in terms of territory of provision. Moreover, it stresses practices both of the operational fuel chain, thanks to analysis of the phenomena of combustion, and of the origin of anatomical deformation and deterioration. This research orientation, too often neglected, has the merit of offering great prospects to archaeological anthracology.

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